Jet Propulsion Laboratory
California Institute of Technology

Toward Understanding Spacecraft Autonomy Computing Needs

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Fault-Tolerant Spaceborne Computing Employing New Technologies
Working Group: Applications

Sandia National Laboratories
Albuquerque, NM
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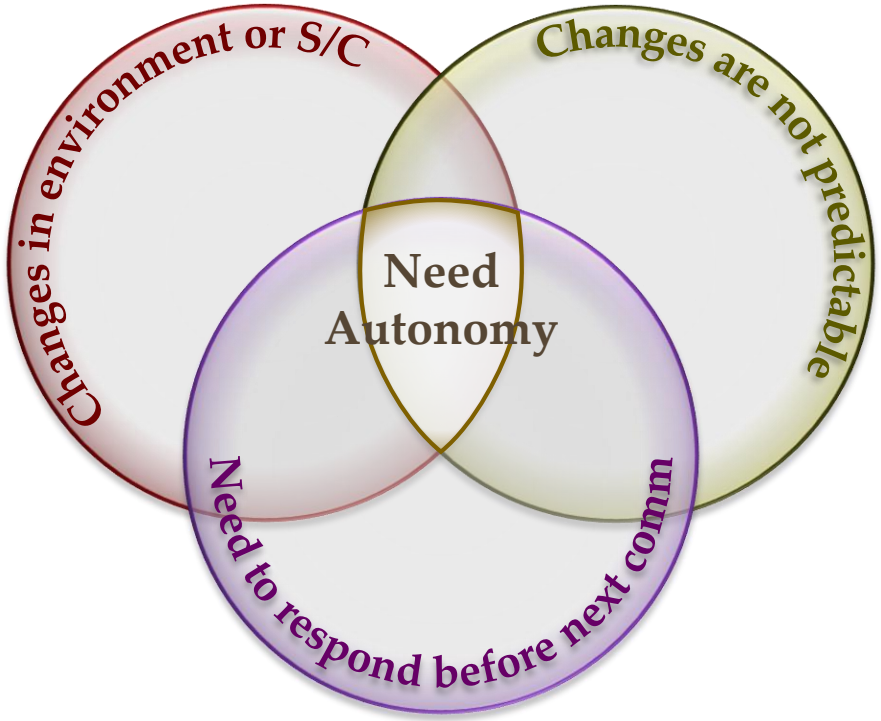
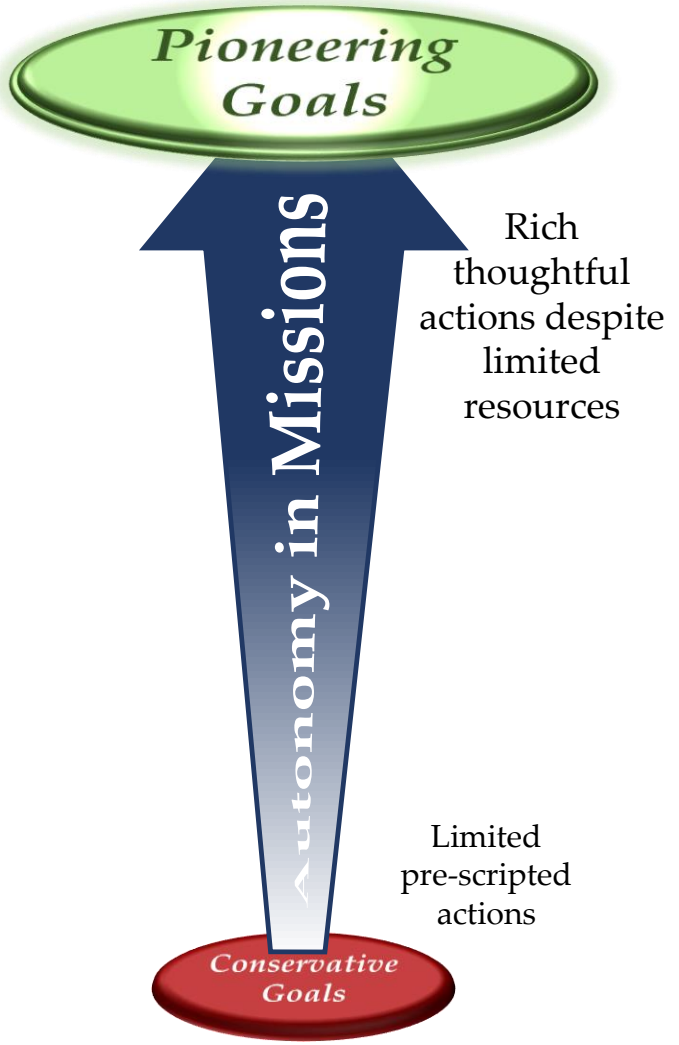
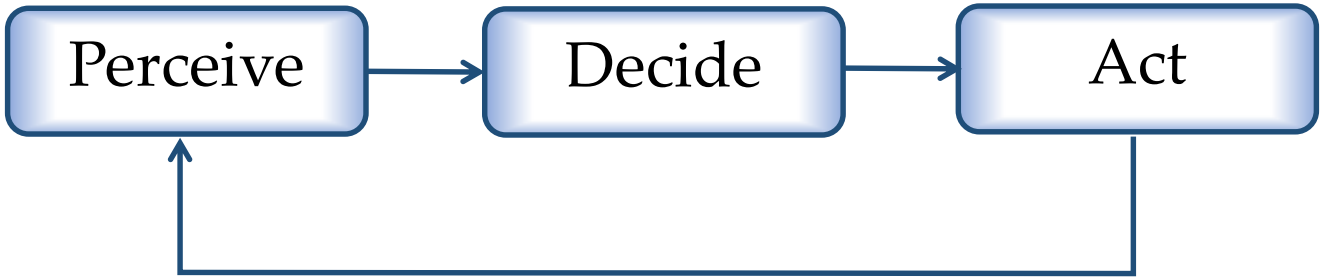
The Need for Autonomy





Autonomy enables pioneering missions:
- Explore new destinations and increase science yield, robustness, operability

What is Autonomy?



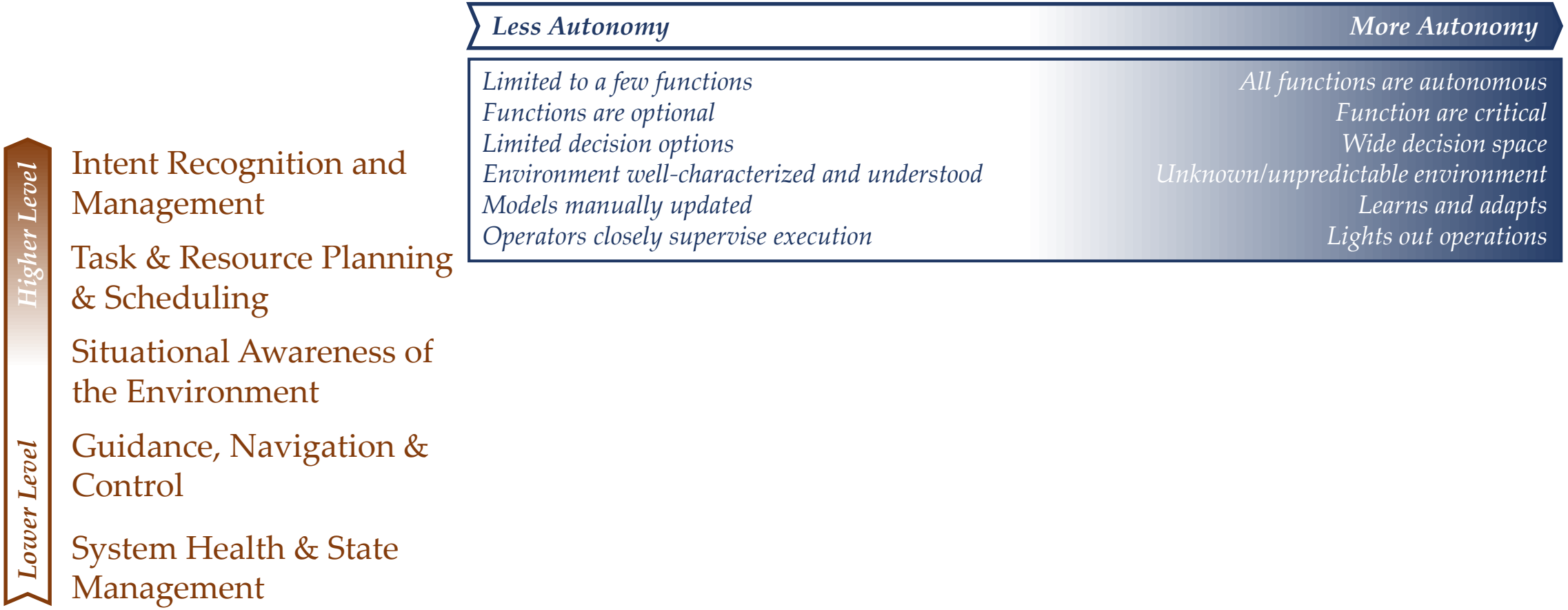
Autonomy: *To make decisions and take actions, in the presence of uncertainty, to execute the mission and respond to internal and external changes without human intervention.*

Hardware
- *Sensing and perception*
- *Computing*
- *System architecture*

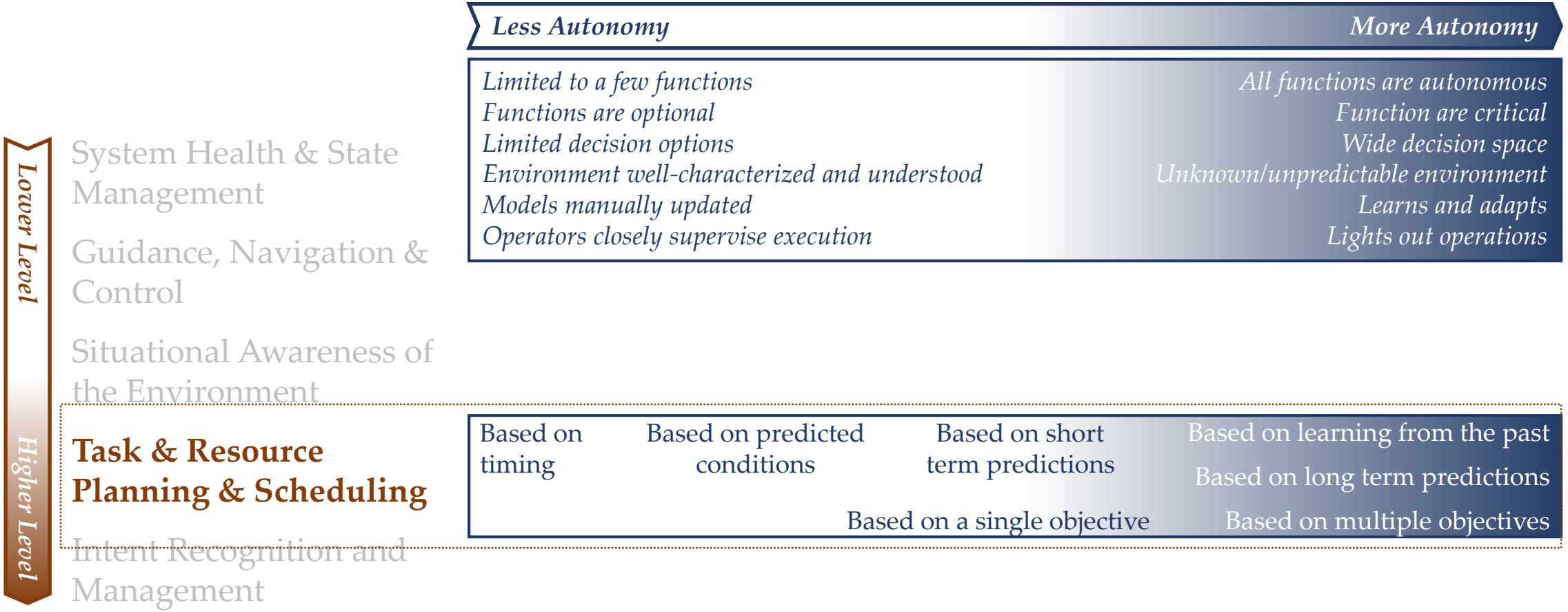
Software
- *Autonomy algorithms*
- *Autonomy architecture and infrastructure*

Systems Engineering
- *System design*
- *Verification and validation*
- *Operations*

Layers and Spectrum of Autonomy



Layers and Spectrum of Task & Resource Planning & Scheduling



Mapping Autonomy Capabilities to Technologies

Capabilities

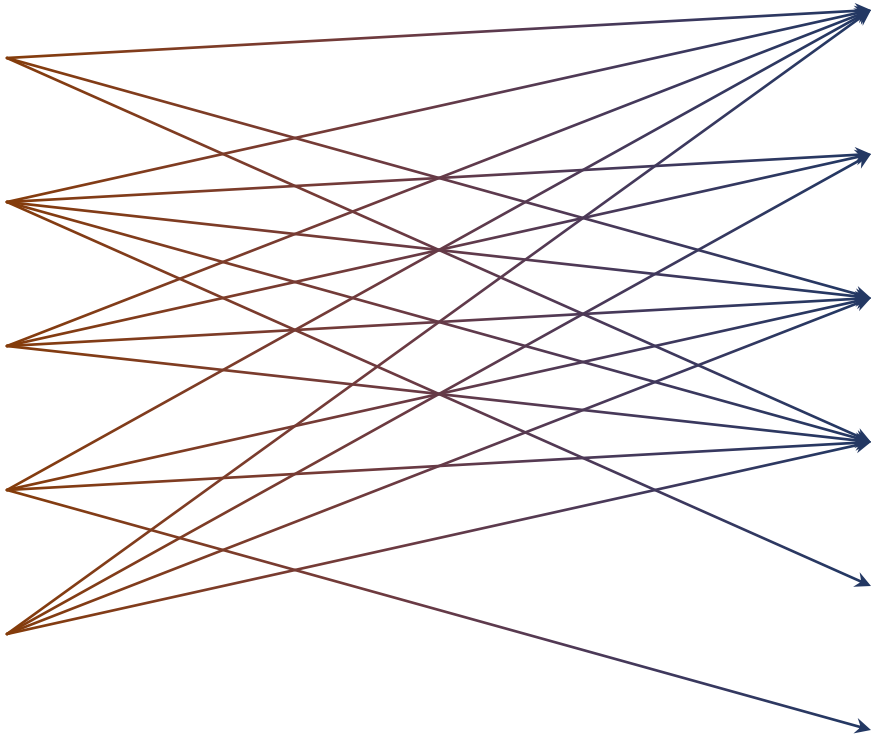
System Health & State Management

Guidance, Navigation & Control

Situational Awareness of the Environment

Task & Resource Planning & Scheduling

Intent Recognition and Management



Technologies

Estimation & Control

Vision

Constraint Checking

Machine Learning

Motion & Path Planning

Task Planning & Scheduling

Technologies for System Health & State Management

Capabilities

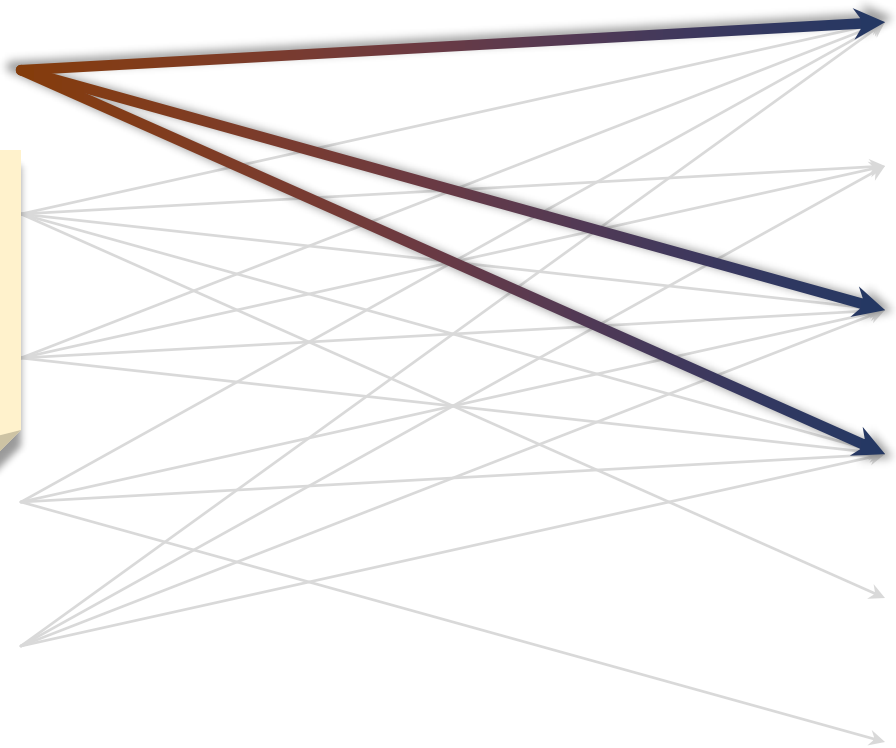
Technologies

System Health & State Management

- State estimation and monitoring
- Knowledge/model-building
- Anomaly detection
- Execution and control
- Diagnosis and prognosis
- Fault response

& Scheduling

Intent Recognition and Management



Estimation & Control

Vision

Constraint Checking

Machine Learning

Motion & Path Planning

Task Planning & Scheduling

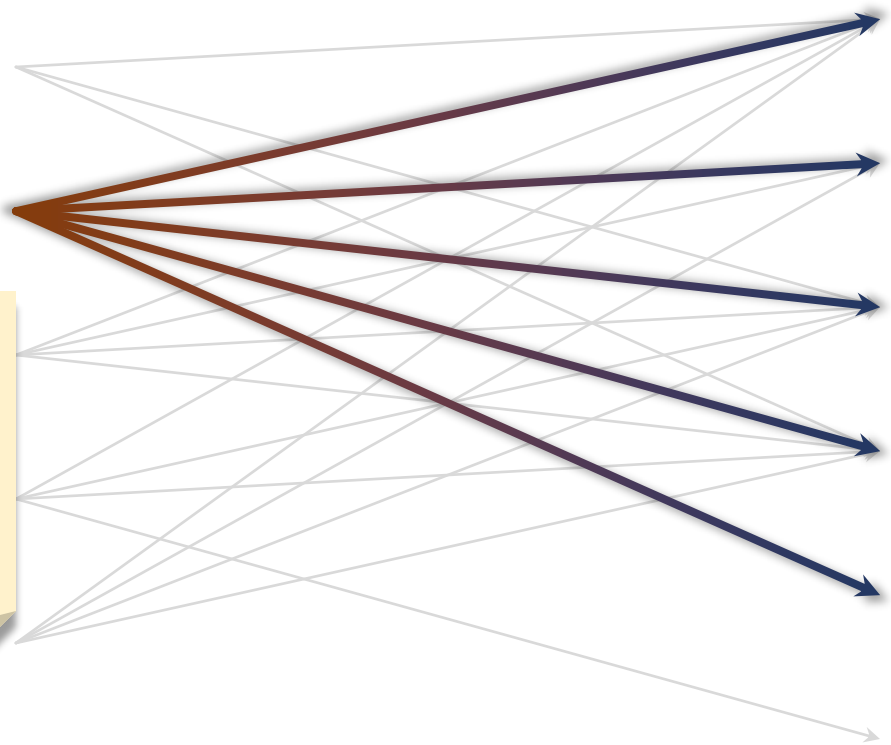
Technologies for Guidance, Navigation & Control

Capabilities

System Health & State Management

Guidance, Navigation & Control

- Hazard assessment
- OpNav
- Mobility and motion planning
- Manipulation
- Autonomous rendezvous and docking
- Learning and adapting



Technologies

Estimation & Control

Vision

Constraint Checking

Machine Learning

Motion & Path Planning

Task Planning & Scheduling

Technologies for Science & Data Analytics

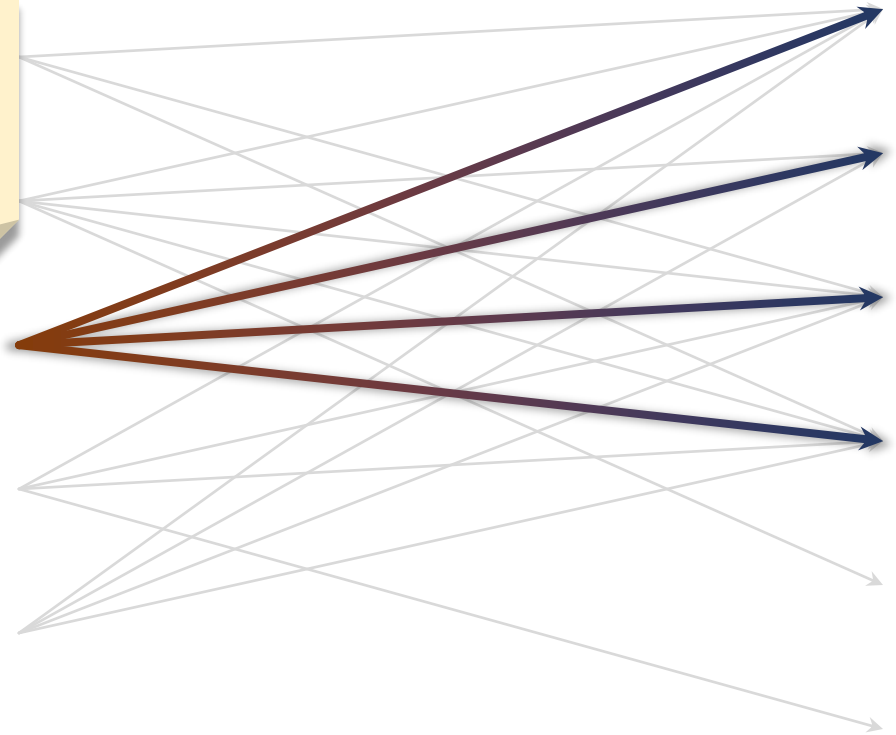
Capabilities

- Sensing and perception
- Hazard Assessment

Situational Awareness of the Environment

Task & Resource Planning & Scheduling

Intent Recognition and Management



Technologies

Estimation & Control

Vision

Constraint Checking

Machine Learning

Motion & Path Planning

Task Planning & Scheduling

Technologies for Task & Resource Planning & Scheduling

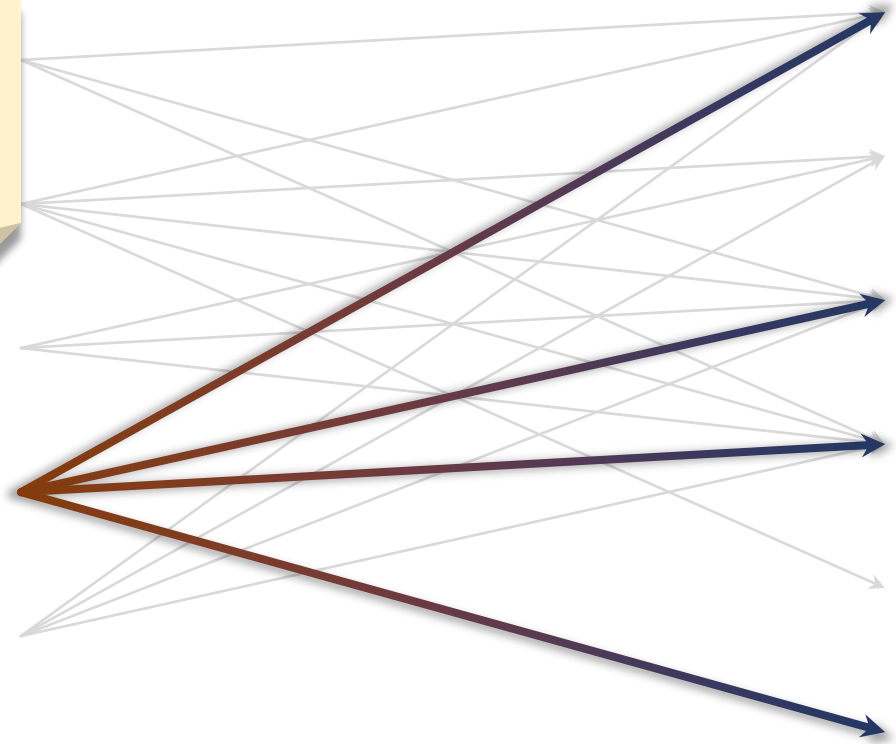
Capabilities

- Event/trend identification
- Mission planning
- Activity and resource planning
- Learning and adapting

Situational Awareness of the Environment

Task & Resource Planning & Scheduling

Intent Recognition and Management



Technologies

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Technologies for Intent Recognition

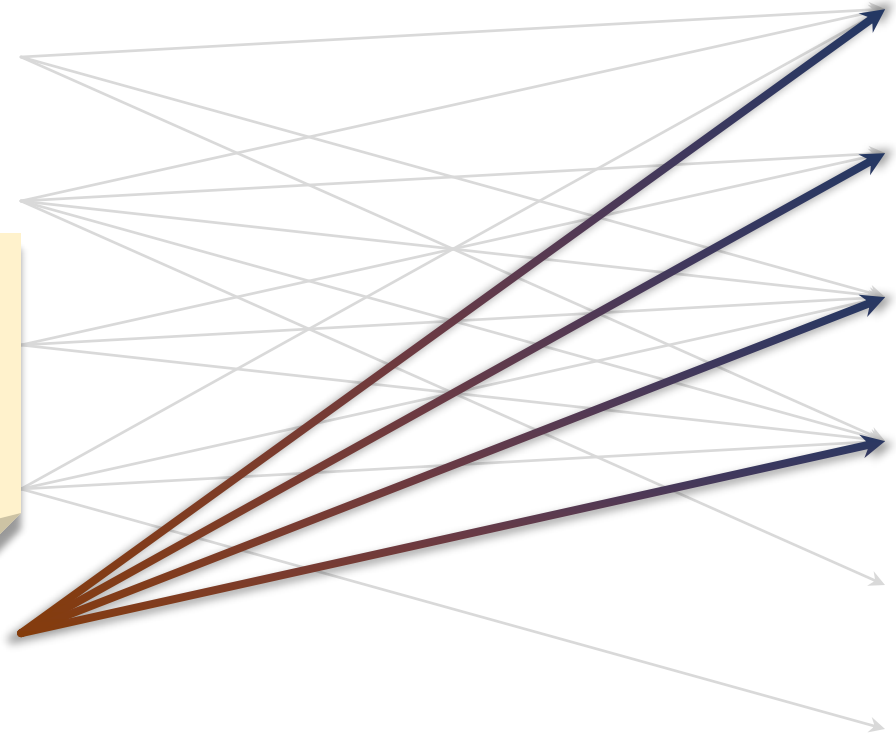
Capabilities

System Health & State Management

Guidance, Navigation & Control

- Knowledge and Intent Conveyance and Understanding
- Prediction of Agents' Behavior
- Goal and Task Negotiation
- Operational Trust

Intent Recognition and Management



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Computing Needs from Autonomy Technology Perspective

Capabilities

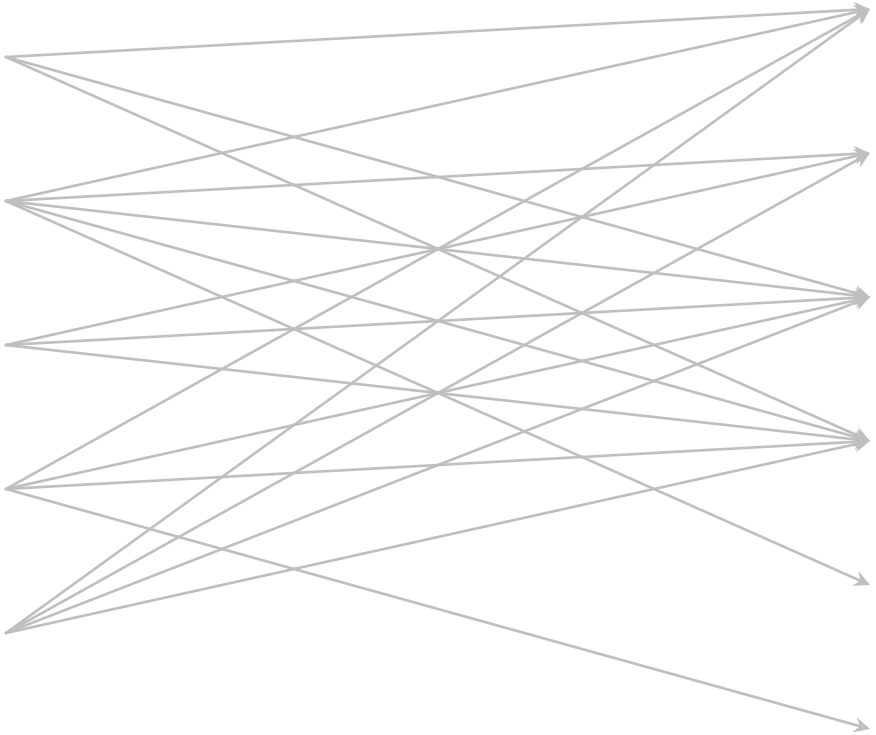
System Health & State Management

Guidance, Navigation & Control

Situational Awareness of the Environment

Task & Resource Planning & Scheduling

Intent Recognition and Management



Technologies

Estimation & Control

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Motion & Path Planning

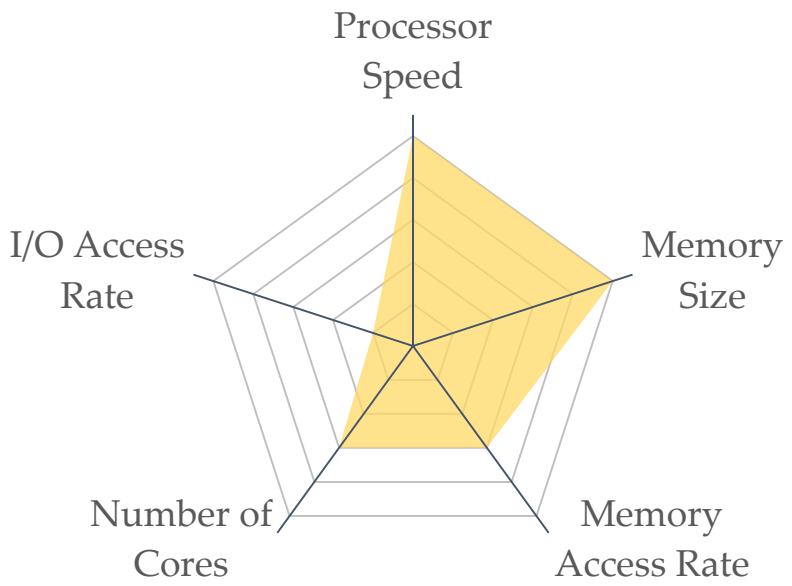
Task Planning & Scheduling

Computing Metrics

- Processing Speed
  - Limits the computation speed (e.g. Clock speed and MIPS)
- Memory Size
  - Limits the size of the autonomy software
- Memory Access Rate
  - Potentially limits the computation speed (e.g. depending on the use of L1/L2/L3/L4 Cache and Memory Bus)
- I/O Access Rate
  - Limits the access speed in reading from or writing to peripheral devices
- Number of Cores
  - Limits parallel processing

Task Planning & Scheduling

- Processor Speed
  - Limits the planning horizon
  - Limits searching more options
  - Limits plan and execution response time
- Memory Size
  - Limits the planning horizon
- Memory Access Rate
  - Limits plan and execution response time
- Number of Core
  - Limits searching more options
- I/O Access Rate
  - Limits check pointing and logging

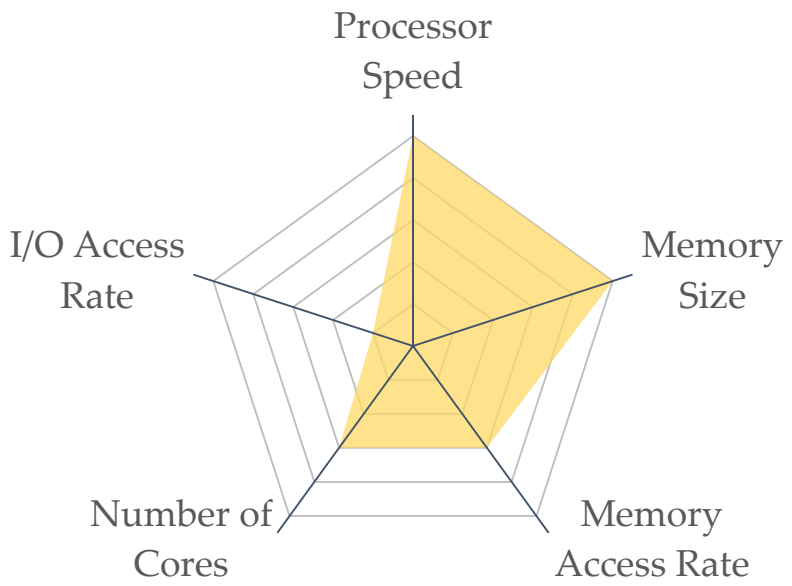


Autonomous Science Experiment (ASE) on Earth Observing-1 (EO-1)

Processor: MIPS R3000 Mongoose-V

- 32bit processor
- 12 MHz

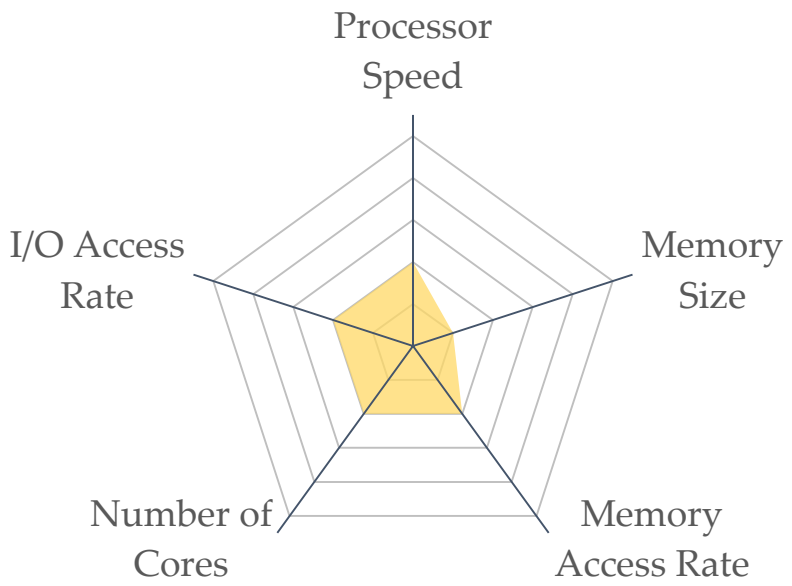
- Processor Speed
  - 4 MIPS shared among SCL, CASPER, and image processing
  - Each CASPER run take 10 minutes
- Memory Size
  - 40 MB RAM of 256 MB total allocated to CASPER
- Memory Access Rate
- Number of Core
  - Single
- I/O Access Rate
  - CASPER was allocated 1MB of filespace
  - 248 bytes of data in its telemetry packet



D. Tran, S. Chien, G. Rabideau, B. Cichy. Flight Software Issues in Onboard Automated Planning: Lessons Learned on EO-1. International Workshop on Planning and Scheduling for Space(IWPSS 2004). Darmstadt, Germany. June 2004

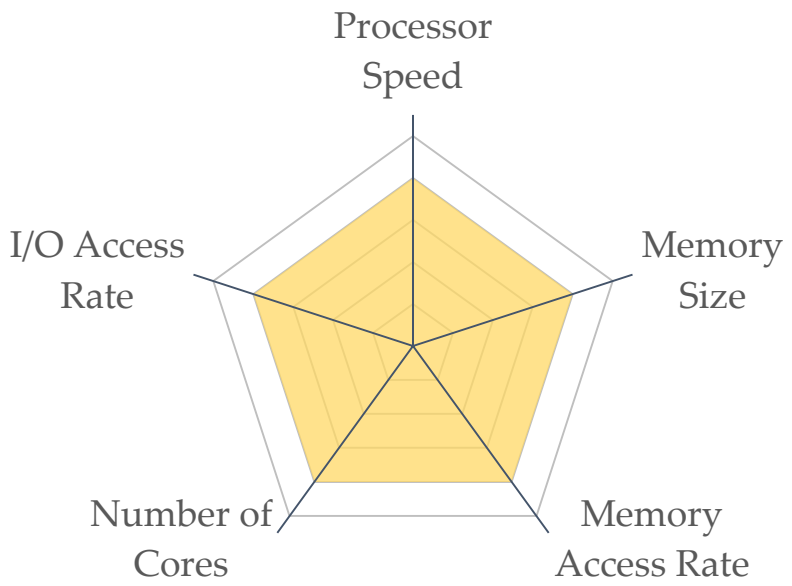
Estimation and Control

- Processor Speed
  - Limits estimation and control computation time (e.g. matrix operations)
- Memory Size
  - Minimal impact
- Memory Access Rate
  - Limits estimation and control computation time
- Number of Core
  - Limits parallel estimation and control computation (e.g. matrix operations)
- I/O Access Rate
  - Limits the time to read from sensors and manipulate actuators



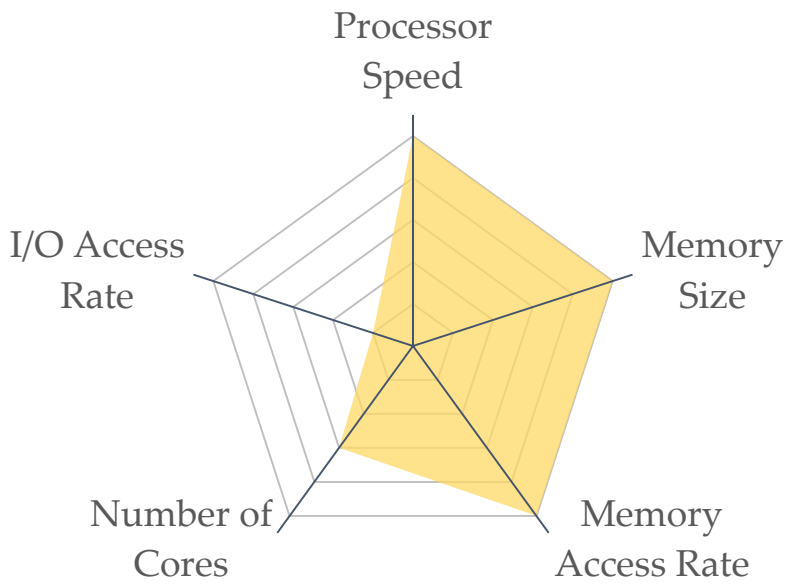
Vision

- Processor Speed
  - Limits vision computation speed (e.g. large matrix operations)
- Memory Size
  - Limits the memory available for vision computation
- Memory Access Rate
  - Limits vision computation speed (e.g. large matrix read/write)
- Number of Core
  - Limits parallel vision computation (e.g. matrix operations)
- I/O Access Rate
  - Limits response time in reading images from external devices



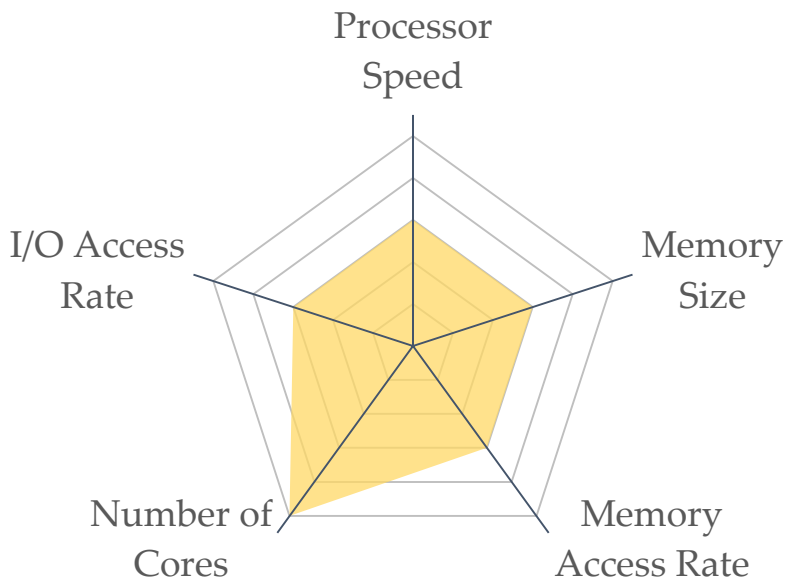
Constraint Checking

- Processor Speed
  - Limits constraint propagation and search speed
- Memory Size
  - Limits search state space
- Memory Access Rate
  - Limits constraint propagation and search tree tracking speed
- Number of Core
  - Limits parallel state space search
- I/O Access Rate
  - Minimal impact



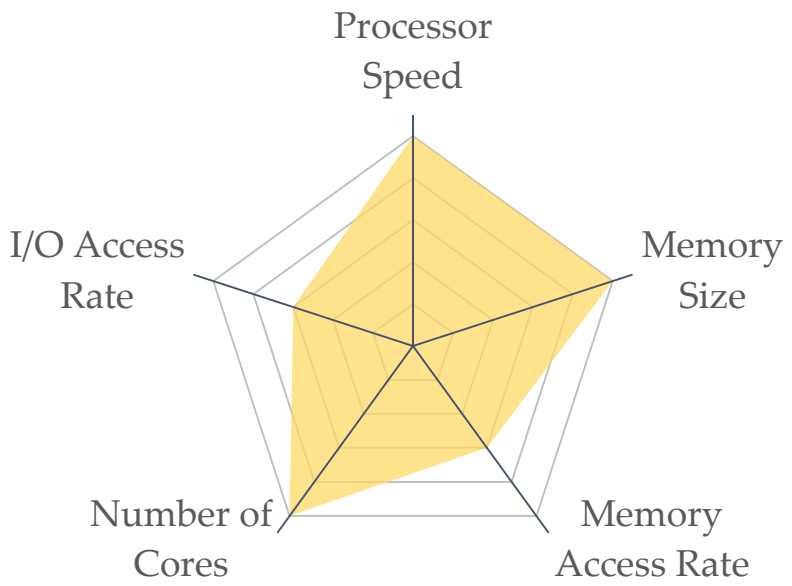
Machine Learning

- Processor Speed
  - Limits learning computation speed (e.g. matrix operations)
- Memory Size
  - Limits the complexity of the learning capability
  - Limits the number of training data in memory
- Memory Access Rate
  - Limits learning computation speed (e.g. matrix operations)
- Number of Core
  - Limits parallel computation (e.g. large matrix operations)
- I/O Access Rate
  - Limits training data read speed



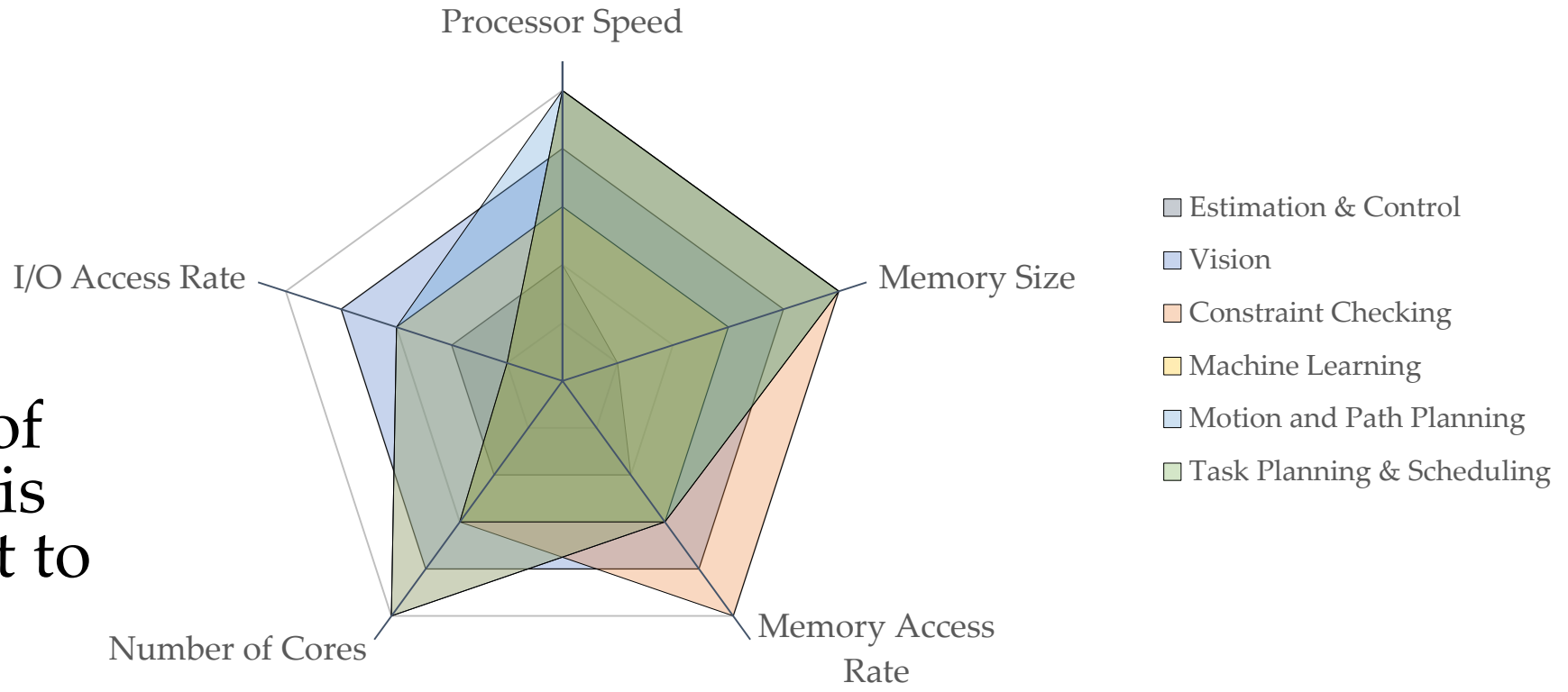
Motion and Path Planning

- Processor Speed
  - Limits the path planning horizon
  - Limits searching more options
  - Limits plan and execution response time
- Memory Size
  - Limits the planning horizon
- Memory Access Rate
  - Limits plan and execution response time
- Number of Core
  - Limits searching more options
- I/O Access Rate
  - Limits the speed of reading from sensors



Summary of Autonomy Computational Needs

What aspect of computation is not important to Autonomy?



Acknowledgements

- The following documents were used as references
  - NASA 2015 OCT Roadmaps, **TA 4: Robotics and Autonomous System**
  - NASA 2016 Autonomous Systems Capabilities Leadership Team's Definition, Scope and Decomposition of Autonomy

Backup

Jet Propulsion Laboratory
California Institute of Technology